Location Centric Distributed Computation and Signal Processing

Parmesh Ramanathan

University of Wisconsin, Madison

Co-Investigators:A. Sayeed, K. K. Saluja, Y.-H. Hu

Project Goals

- Tailor communication primitives for location-centric computing (Task 1)
- Develop robust, multi-resolution signal processing algorithms (Task 2)
- Develop strategies for fault-tolerance and self-testing (Task 3)

Task 1 Accomplishments (1/4)

On paper

- Developed network API for location-centric computing (UW-API)
  - Sender controlled
- Developed routing scheme for sensor networks (UW-Routing)
  - Location-aided
  - On demand route establishment
  - Route caching

Task 1 Accomplishments (2/4)

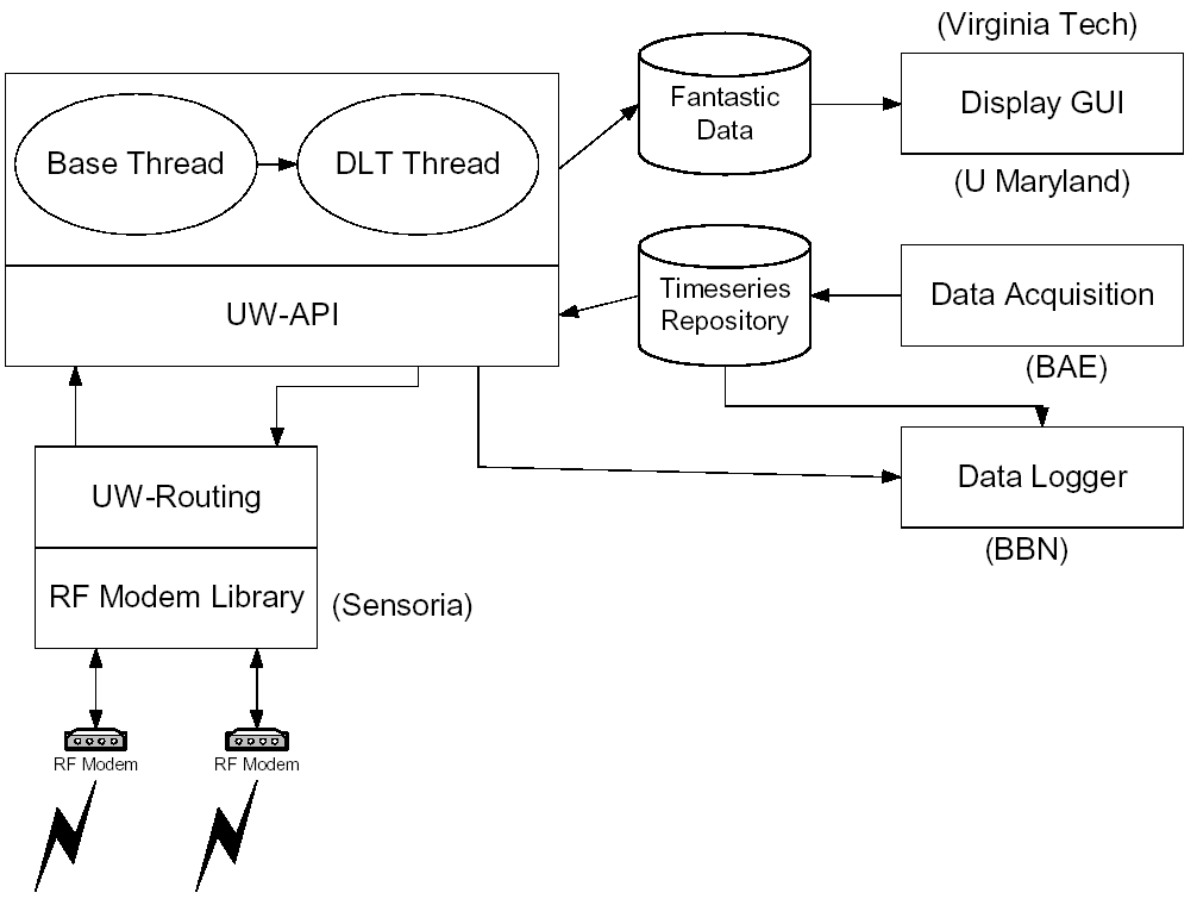


Figure D.1.1. Software architecture of our implementation on WINS2.0.

On WINSNG2.0 nodes

- Implemented UW-API and UW-Routing
- Integrated with CSP algorithms
- Integrated with other SITEX02 modules
- Participated in SITEX02

Task 1 Accomplishments (3/4)

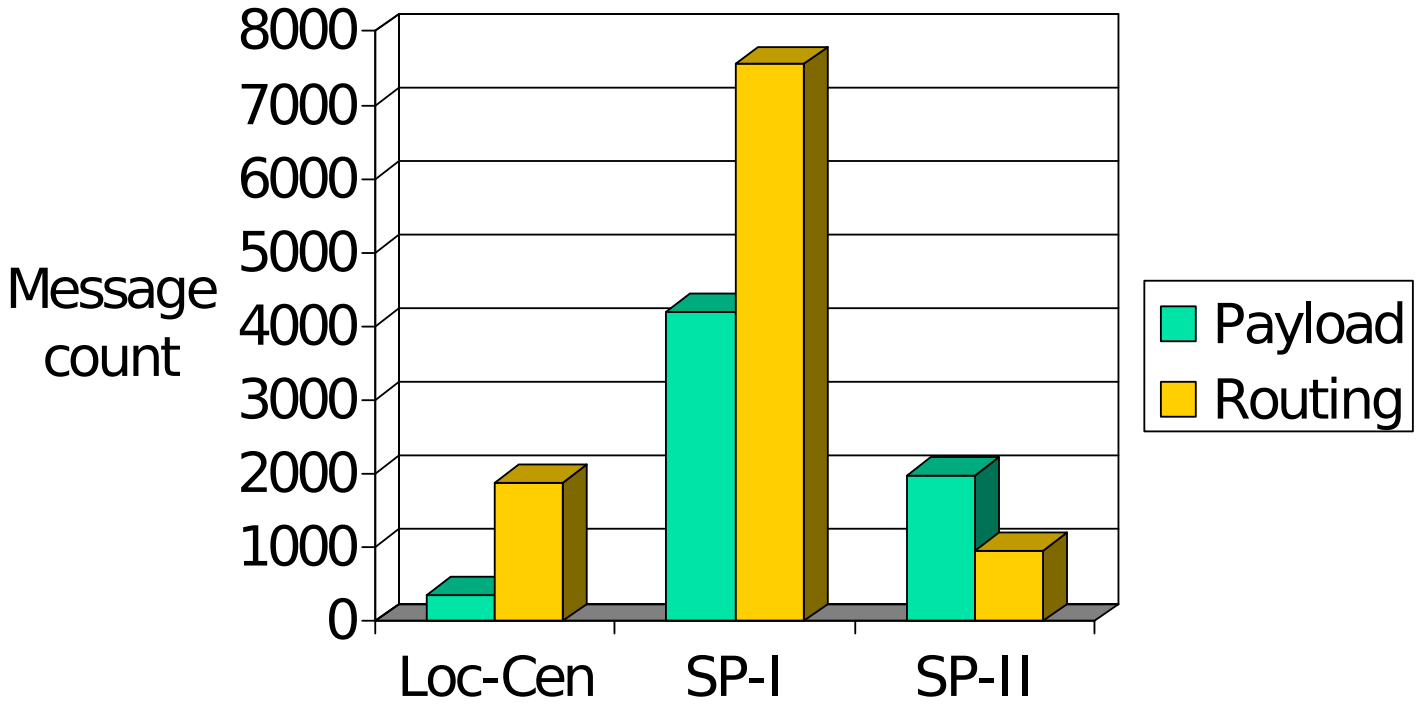
On ns-2

- Implemented UW-API and UW-routing
- Compared the performance to pre-SITEX02 diffusion routing and ISI's network API for a target tracking application

ns-2 Sample Results

- Implemented a target tracking application in a sensor field using three approaches using ns-2
  - *SP-I* (Subscribe-Publish-I): Approach being used in SITEX02 operational experiment
  - *Loc-Cen*: Our push-based approach
  - *SP-II*: Approximating the push-based approach using ISI's network API

Sample Results



Payload: Data exchange between sensors for CSP

Routing: Messages sent purely to maintain network-leve
connectivity

Task 1 Accomplishments (4/4)

On Linux Workstations

- Emulated Sensoria's RF modem API using sockets over Ethernet
- Implemented playback mechanism to replay SITEX02 data
- Can synchronously replay on a network of workstations

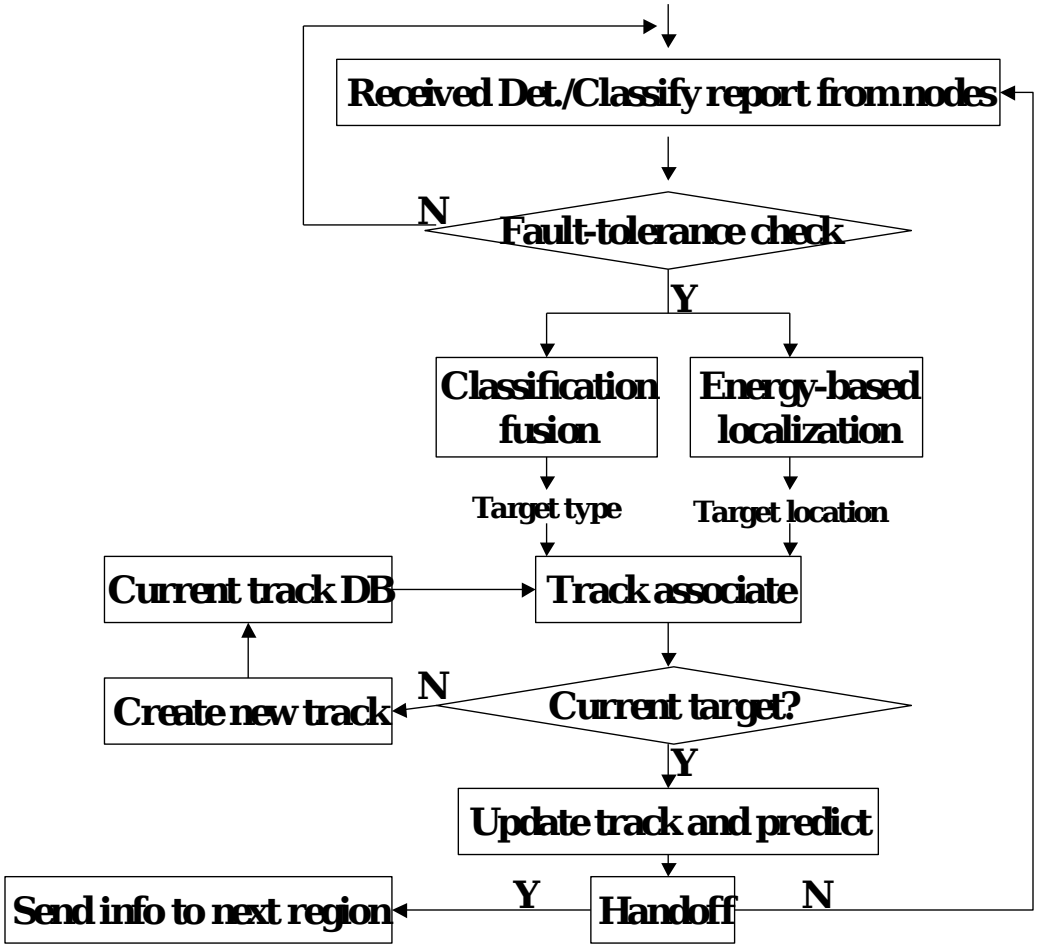
Task 1: Plan for 2002

- Compare performance with post-SITEX02 release of diffusion routing in ns-2
- Compare the performance on SITEX02 data
- Enhance UW-API to better support fault-tolerance

Task 2 Accomplishments

- Developed CSP algorithms for detection, classification, localization, and tracking using acoustic sensors
- Evaluated the algorithms using Matlab
- Implemented the algorithms on WINSNG2.0 nodes using UW-API for collaboration
- Presently evaluating algorithms through playback of SITEX02 data

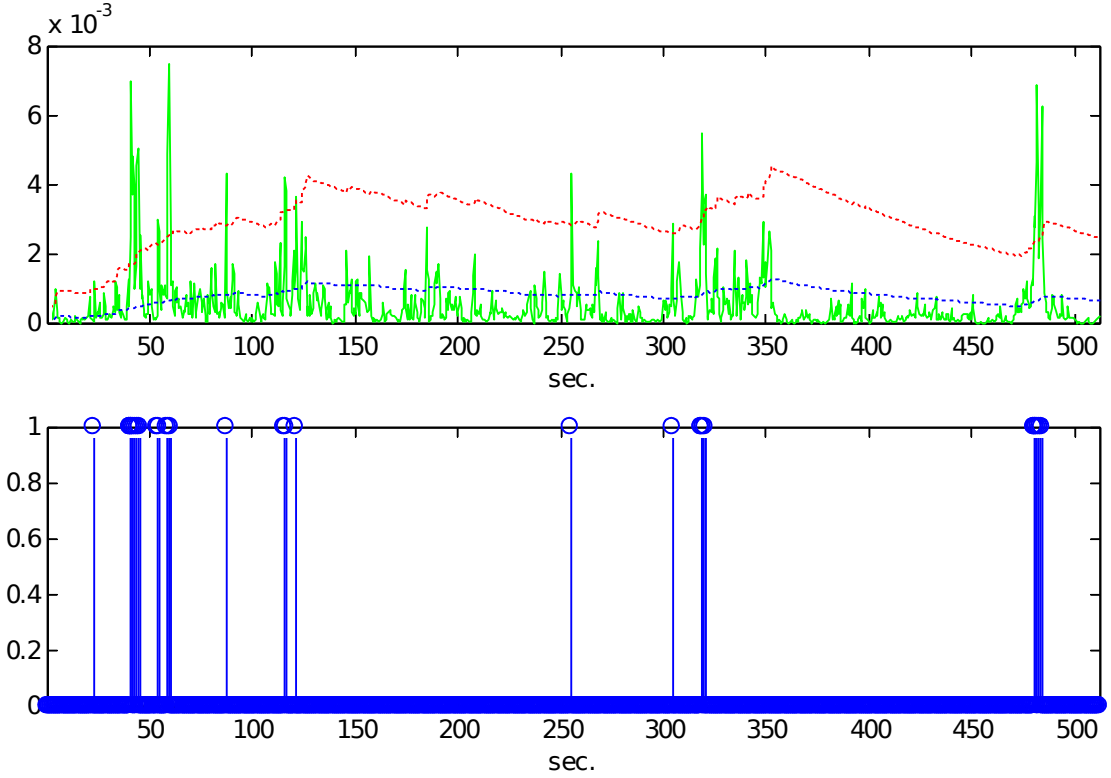
UW-CSP Algorithms



- At each node
  - Energy detection
  - Target classification
- In each region
  - Region detection and classification
  - Energy based localization
  - Least square tracking
  - Hand-off policy

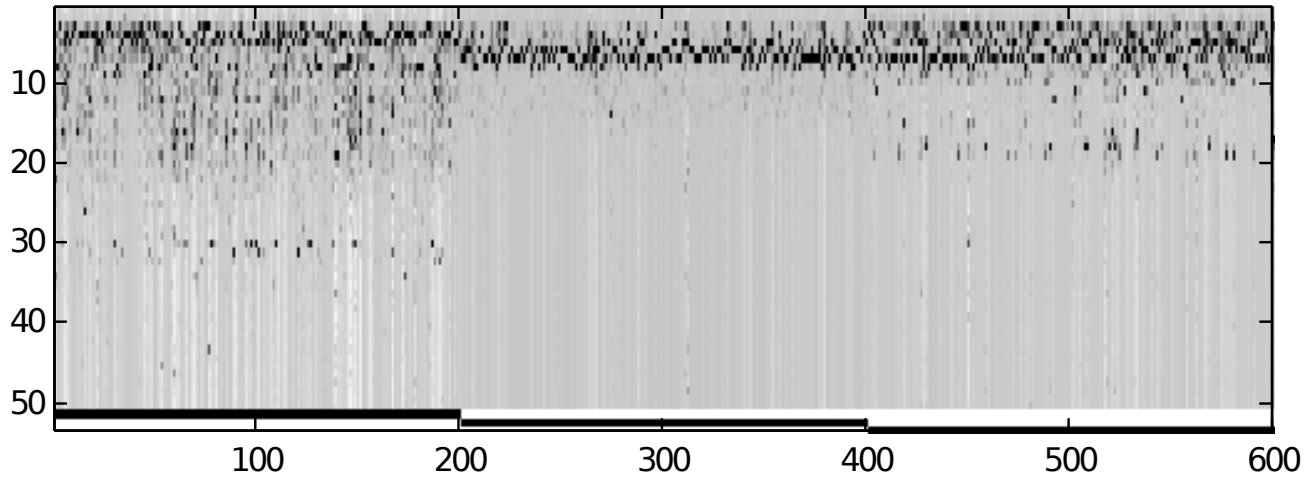
Sample CFAR Detection Result

- Sitex02 node 4 channel 1, recorded on Mon Nov 13, 2001 15:17:24 528 msec to 15:45:02 84 msec.
- Length: 8 minutes 32 seconds



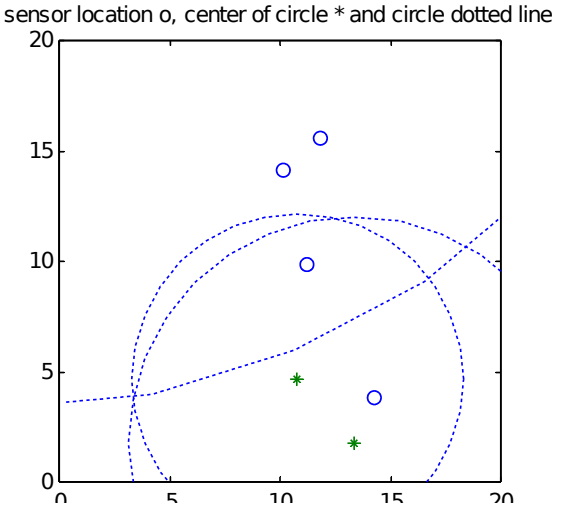
Green line: energy @ 0.75s interval
Upper dash line: 3σ
Lower dash line: σ

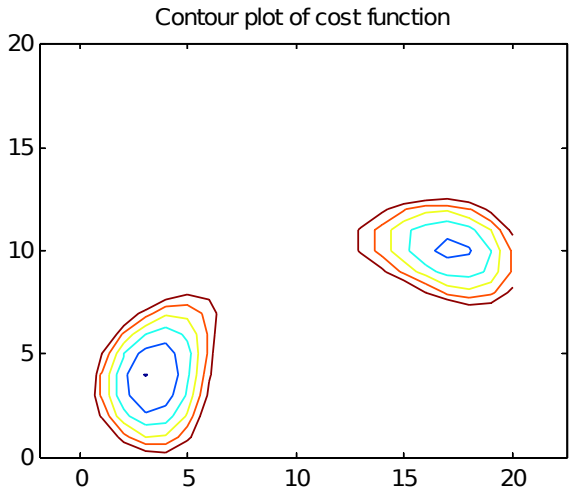
Sample Feature Vectors

- Currently, 3 classes: AAV, DW, and LAV
- Trained with Sitex00 broadband data from BAE and Xerox (AAV and LAV), and Sitex02 DW data.
- 

Energy Based Localization

- Factors affecting location estimate accuracy:
  - Energy estimate *y(t)*
  - Sensor locations r_i
  - Energy decay exponents α
  - Sensor gain variation g_i
- As such, the *(n-1)* energy ratio circles may not intersect at a unique position
- Nonlinear cost function that may contain multiple local minimum:





Robust Least Square Tracking

- Model x(t) and y(t) as polynomials of time t

$$x(t) = a(0) + a(1)t + \cdots + a(m)t^m$$

$$y(t) = b(0) + b(1)t + \cdots + b(n)t^n$$

- Solve polynomial coefficients using least square solution.
- Predict future position by fitting future time into model.
- Can handle non-even time samples in CPA method.
- Adaptive update formula with forgetting factor.

- Implementation:
  - Easy to compute
  - Few parameters to pass

$$\begin{bmatrix} 1 & t_k & t_k^2 \\ / & / t_{k-1} & / t_{k-1}^2 \\ M & M & M \\ / & / t_{k-n+1}^{n-1} & / t_{k-n+1}^{n-1} \end{bmatrix} \begin{bmatrix} a(0) \\ a(1) \\ a(2) \end{bmatrix} = \begin{bmatrix} x(t_k) \\ / x(t_{k-1}) \\ M \\ / x(t_{k-n+1}^{n-1}) \end{bmatrix}$$

Adaptive update formula using plane rotation

$$\underbrace{\begin{bmatrix} R_{11} & R_{12} & R_{13} \\ 0 & R_{22} & R_{23} \\ 0 & 0 & R_{33} \\ 0 & 0 & 0 \\ M & M & M \\ 0 & 0 & 0 \end{bmatrix}}_{W(k)} \begin{bmatrix} a(0) \\ a(1) \\ a(2) \end{bmatrix} = \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ z_1 \\ M \\ z_{n-3} \end{bmatrix}$$

Parameters to pass to another region

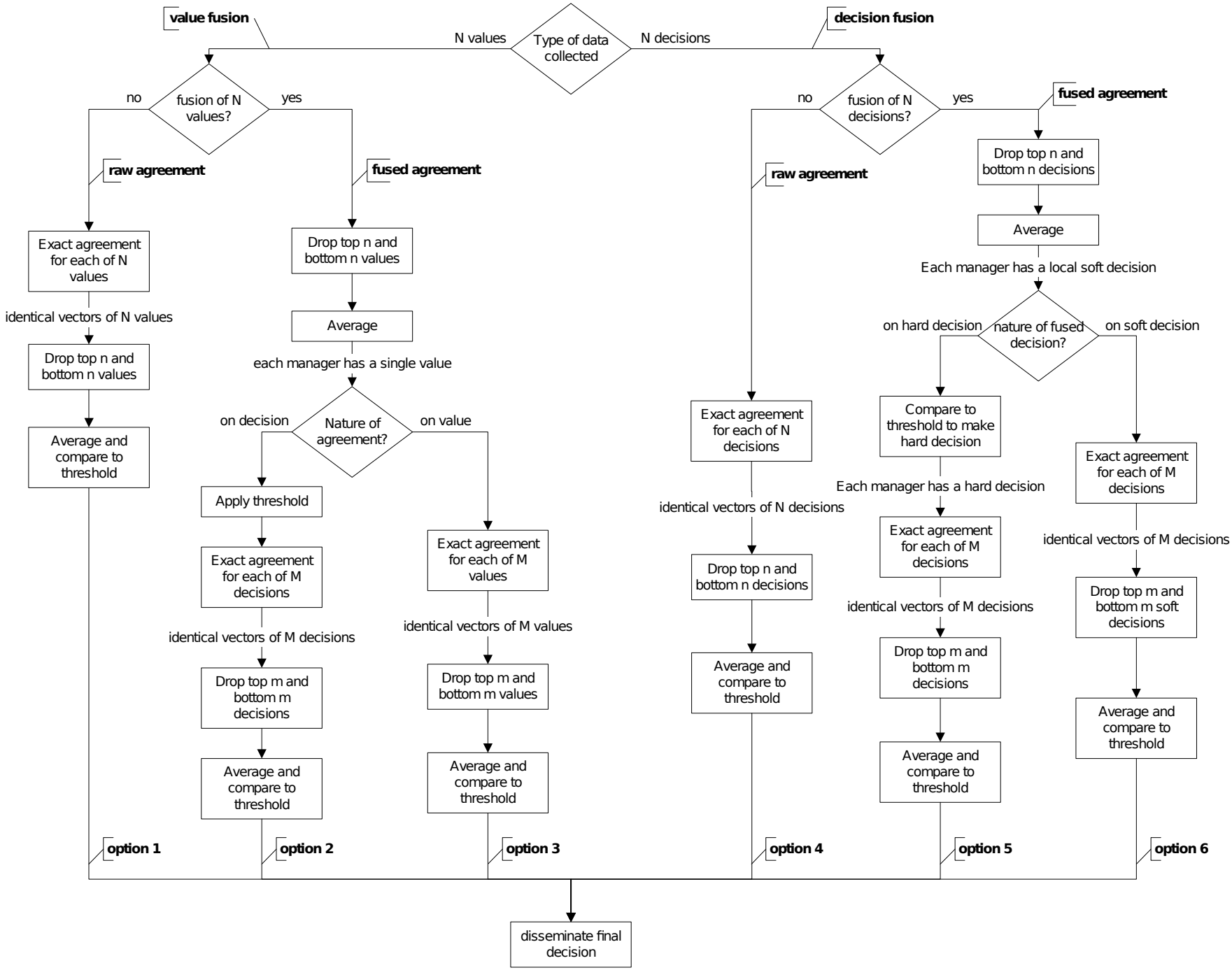
Task 2: Plan for 2002

- Work with Sitex00 and Sitex02 time series
- Improve detection using classification results
- Improve classification by
  - Finding better feature
  - Feature reduction
  - Different classifiers
- Improve localization
  - Better implementation
  - Multiple targets
- Improving tracking
  - Multiple targets
  - Track association

- Multi-modal processing
  - Node modal fusion
  - Region detection and classification fusion
  - Localization using seismic time series and incorporate PIR modality

Task 3 Accomplishments (1/3)

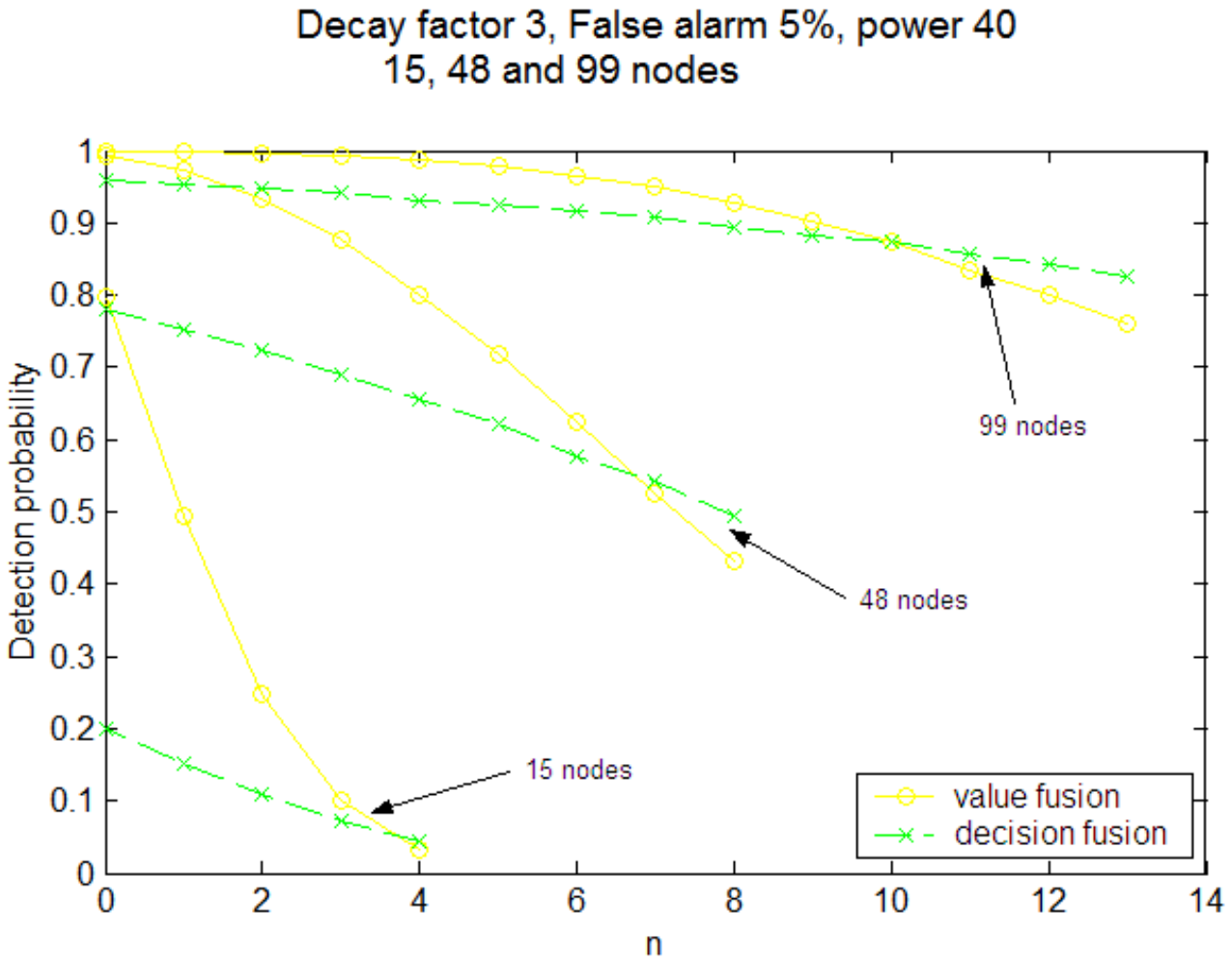
- Developed fault-tolerant centralized fusion algorithm for target detection
  - Presented at April 2000 PI meeting
  - Results presented at FUSION 2001 conference
  - Efficient for sparse sensor networks
- Developed fault-tolerant hierarchical fusion algorithms for target detection
  - Paper submitted to DSN 2002


value fusion
N values
Type of data collected
N decisions
decision fusion
no
fusion of N values?
yes
raw agreement
fused agreement
Exact agreement for each of N values
identical vectors of N values
Drop top n and bottom n values
Average and compare to threshold
Drop top n and bottom n values
Average
each manager has a single value
on decision
Nature of agreement?
on value
Apply threshold
Exact agreement for each of M decisions
identical vectors of M decisions
Drop top m and bottom m decisions
Average and compare to threshold
Exact agreement for each of M values
identical vectors of M values
Drop top m and bottom m values
Average and compare to threshold
option 1
option 2
option 3
no
fusion of N decisions?
yes
fused agreement
raw agreement
Exact agreement for each of N decisions
identical vectors of N decisions
Drop top n and bottom n decisions
Average and compare to threshold
Drop top n and bottom n decisions
Average
Each manager has a local soft decision
on hard decision
nature of fused decision?
on soft decision
Compare to threshold to make hard decision
Each manager has a hard decision
Exact agreement for each of M decisions
identical vectors of M decisions
Drop top m and bottom m decisions
Average and compare to threshold
Exact agreement for each of M decisions
identical vectors of M decisions
Drop top m and bottom m soft decisions
Average and compare to threshold
option 4
option 5
option 6
disseminate final decision

Task 3 Accomplishments (2/3)

- For centralized and hierarchical approaches, developed analytic model to characterize
  - probability of detection
  - Probability of false alarm
  - Probability of failure
- Simulated the approaches in Matlab

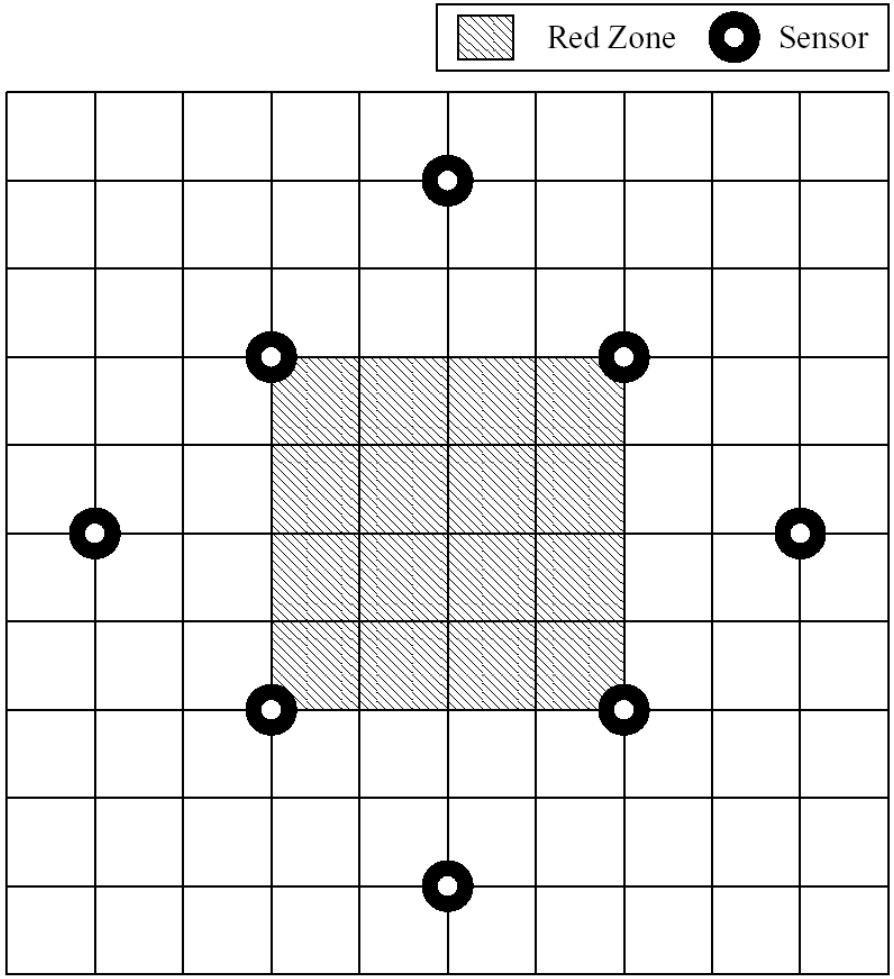
Value versus Decision Fusion



Task 3 Accomplishments (3/3)

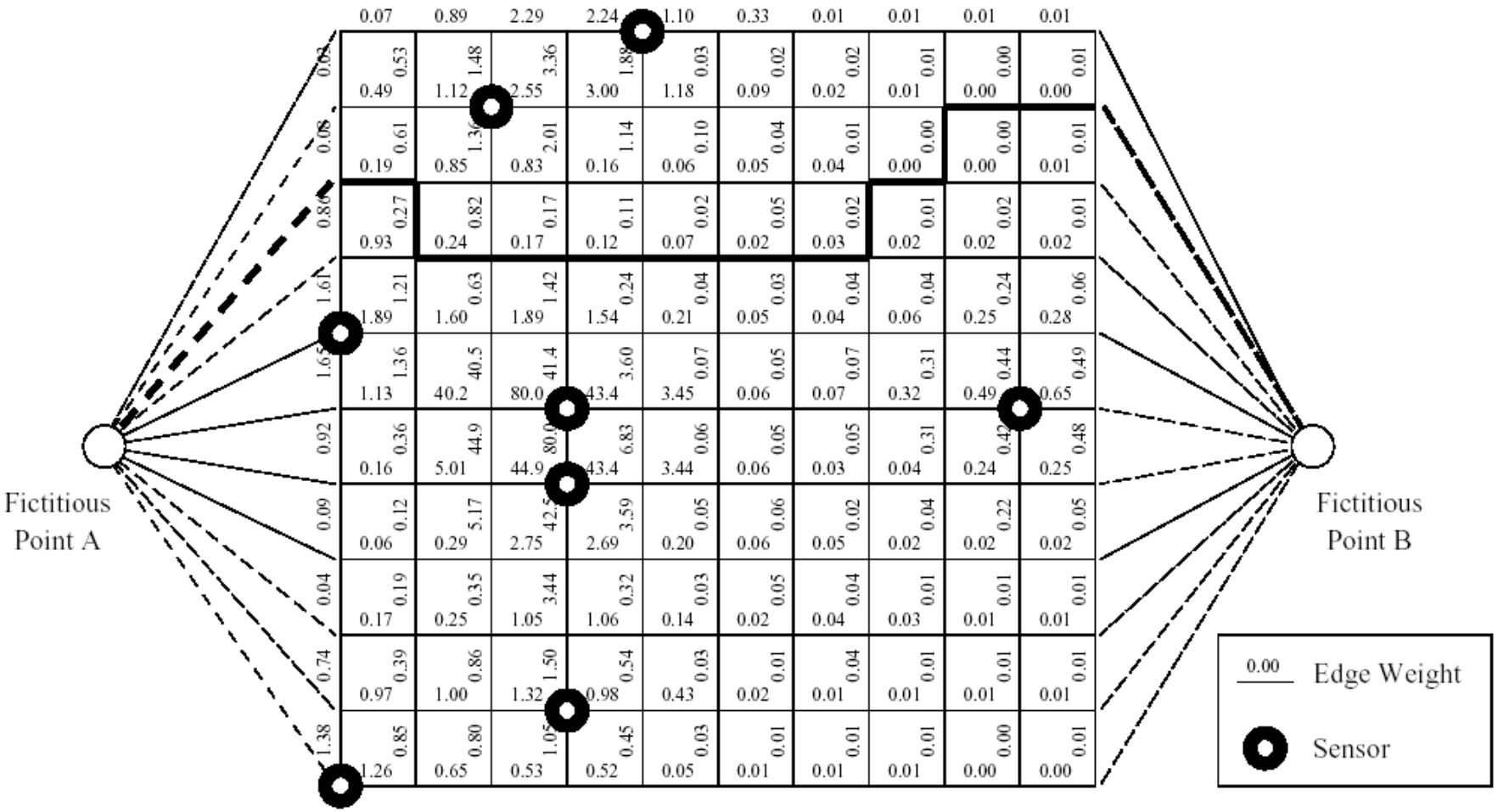
- Developed a better approach to characterize sensor deployments with respect to unauthorized traversal and monitoring
- Implemented the approach in Matlab
- Paper submitted to MobiHoc 2002

Unauthorized Traversal and Monitoring



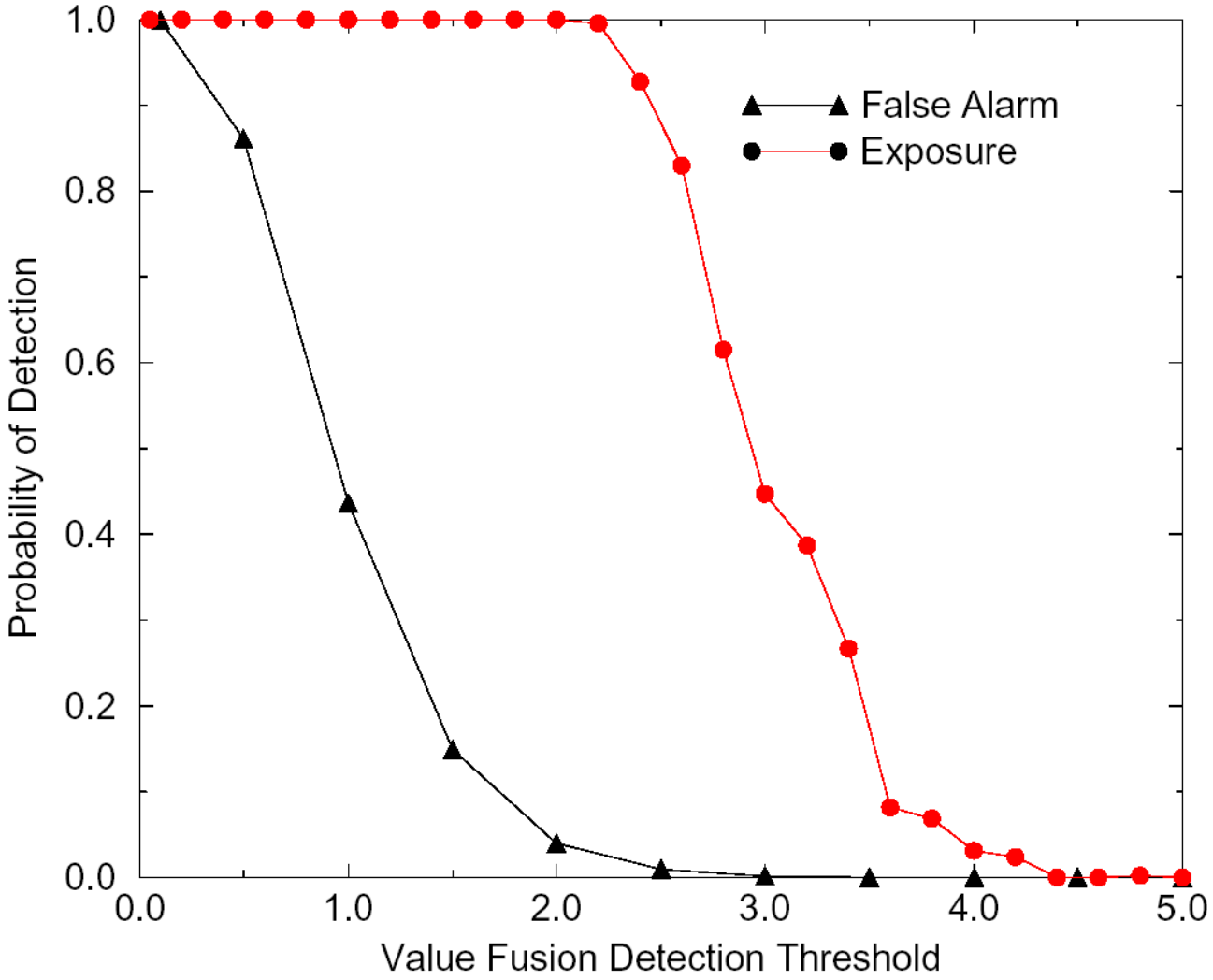
- Exposure:Probability of detection
- Deals with noise
  - Tradeoff between false alarm and exposure
- Incorporates value and decision fusion algorithms
- Can deal with sensor faults

Unauthorized Traversal



Threshold = 3.0, Detection Probability of the Path = 0.451

Unauthorized Travesal



Task 3: Plan for 2002

- Evaluate impact of faults on target tracking using SITEX02 data
- Develop fault-tolerant algorithms for localization and tracking
- Investigate methods for diagnosing faulty sensors